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No

MSC-IN-EG-65-31

PROJECT APOLLO

OPTICAL TRACKER SUN INTERFERENCE RESULTS

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HOUSTON, TEXAS

July 19, 1965

N70-75902

(ACCESSION NUMBER)

(THRU)

09

(PAGES)

None

(CODE)

TMX-65304

(NASA CR OR TMX OR AD NUMBER)

(CATEGORY)

## OPTICAL TRACKER SUN INTERFERENCE RESULTS

### Introduction

This report presents the results of a study performed to determine the effects of sun interference on the use of the optical tracker for navigation during LEM ascent and rendezvous.

The digital computer program used for the linearized error analysis, as described in MSC Internal Note Number 65-EG-11, was altered to handle multiple impulse transfers, and to include sun interference constraints on optical tracker measurements. This simulation was then used to investigate a restricted set of sun interference effects on the following types of rendezvous transfers:

1.  $130^{\circ}$  (a limiting case of the short transfers advocated by MIT)
2.  $180^{\circ}$  (the nominal Hohmann transfer)
3.  $230^{\circ}$  (abort)
4. Double Hohmann with 60 n.m. intermediate altitude
5. Double Hohmann with 120 n.m. intermediate altitude
6. MPAD, Hohmann transfer to 30 n.m. altitude, circularize and hold parking orbit for 26 minutes,  $140^{\circ}$  transfer to rendezvous ( $45^{\circ}$  West landing site).
7. MPAD, Hohmann transfer to 30 n.m. altitude, circularize and hold parking orbit for 58 minutes,  $140^{\circ}$  transfer to rendezvous ( $45^{\circ}$  East landing site).

The results are presented in the form of nominal and RMS fuel requirements, and dispersions and uncertainties at the approximate docking interface. The conclusion is that sun interference is not a serious limitation on the performance of the mission.

### Multiple Impulse Transfers

The program modification to handle multiple impulse transfers (cases 4, 5, 6, and 7, of those investigated) required an assumption on the guidance technique to be used in these cases. It was assumed that a Lambert's law guidance would be used on a point-to-point fixed time of arrival basis, i.e., that the guidance would always try to null position errors at the next point where a nominal transfer velocity impulse was to

be inserted. This assumption was based on the fact that it is fairly difficult to implement explicit guidance with intermediate impulses. A series of tests revealed that it is necessary to use active mid-course guidance throughout the trajectory, since the Double Hohmanns, in particular, are very sensitive to out-of-plane errors at the point where the intermediate impulse is applied, and in general omission of mid-course guidance during any phase was eventually more costly than using it.

### Sun Interference Constraints

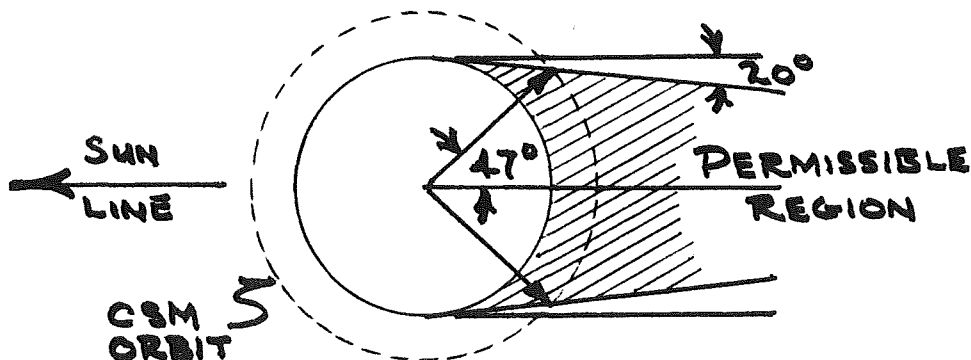
The constraint that the tracker line of sight not lie within a  $30^\circ$  half-angle cone of the sun-line was imposed by the following test:

$$\rho \cdot u_{SL} > \cos 30^\circ \Rightarrow \text{no sighting}$$

where  $\rho$  is the line of sight unit vector

$u_{SL}$  is a unit vector toward the sun

However, the shadow of the moon permitted a sighting provided that the CSM was  $20^\circ$  "within" the shadow, i.e.,



This was tested by:

$$-u_{CSM} \cdot u_{SL} > \cos 47^\circ \Rightarrow \text{sighting}$$

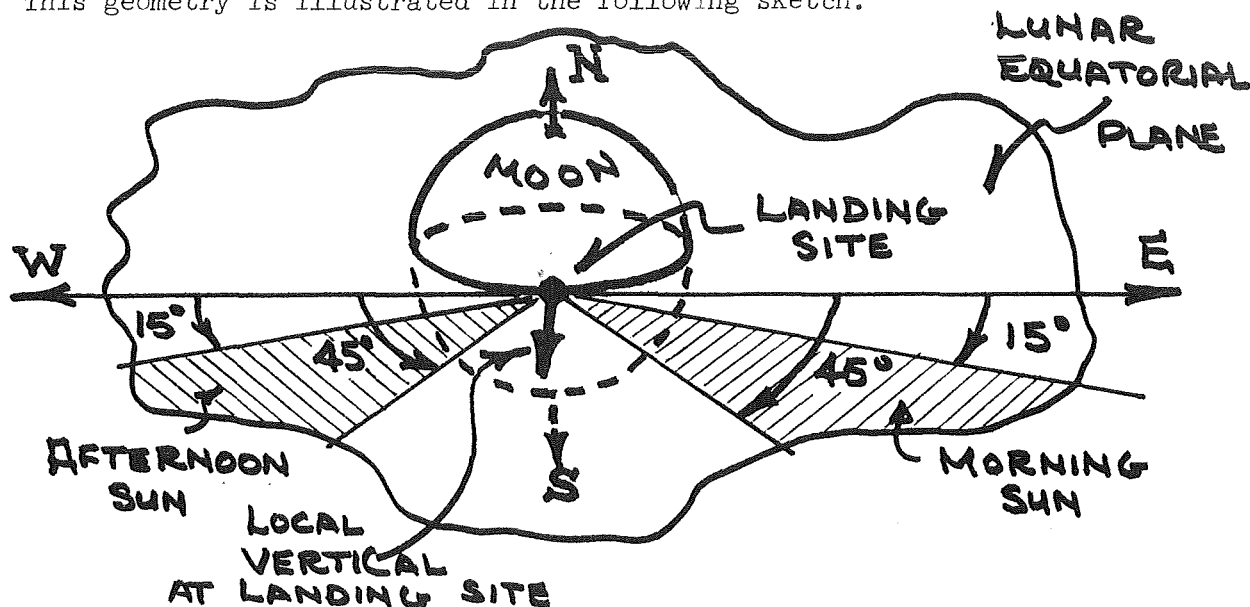
Where  $u_{CSM}$  is the CSM position unit vector from the moon's center.

This criterion should be reasonable, since the moon's shadow should reduce the sun interference effects enough to make sighting within  $20^\circ$  (in the critical case) tolerable.

### Sun-line Geometry

A simplified set of sun-line conditions was considered to expedite this investigation. Based on a constraint proposed by MPAD, only

sun-lines with elevation of 15 to 45 degrees with respect to the local vertical at the landing site were considered. The original constraint was broadened by considering both "morning" and "afternoon" elevations. This geometry is illustrated in the following sketch.



The sun was assumed to lie in the lunar equatorial plane, and rotation of the sun-line with time was not accounted for. Specifically, four cases were treated: 15 degree elevations with east and west components (low morning and afternoon sun), and 45 degree elevations with east and west components (high morning and afternoon sun).

#### Instrument Accuracy

An optical tracker with line-of-sight error characterized by a variance of  $1. \times 10^{-8}$  rads. and zero mean was simulated. The remaining details of handling platform alinement errors, and the like are reported in MSC Internal Note Number 65-EG-11. This tracker accuracy is optimistic, but a somewhat larger error should still produce the same relative results for the evaluation of sun-line interference effects.

#### Further Assumptions

The effect of earth shine interference on the optical tracker operation was not included. This is relatively minor, since it is a narrow band effect. A more important omission was neglecting the effects of CSM ephemeris uncertainties on the navigation. This should not influence the evaluation of sun-line interference on any of the trajectories examined, but should impose a significant penalty on the long term (i.e., Double Hohmann and MPAD) transfers relative to the shorter transfers in the nominal case. This effect was not included because it is not yet

clear how on-board navigation will handle it, and because a good estimate of the covariance of uncertainties of the lunar orbital navigation system for current and predicted accuracies is not available.

### Results

The results of this investigation appear in Table I, where several quantities of interest for a nominal case and applicable sun-line elevations for each of the transfer types are listed. Sun-line elevations that do not interfere with any sightings are not listed. The tabulated quantities requiring explanation are:

Mid-course corrections - the number of corrections inserted as determined by a noise ratio test. For the multiple impulse transfers, the number of corrections on each arc is denoted.

Mid-course  $\Delta V$  RMS - sum of the square roots of the traces of the velocity covariance matrices associated with the mid-course corrections.

Terminal corrections - the number of correction points on the range/range-rate rendezvous schedule.

Summed  $\Delta V$  RMS - sum of the square roots of the traces of the velocity covariance matrices associated with the terminal corrections plus the mid-course  $\Delta V$  RMS.

Nominal  $\Delta V$  - the sum of all velocity increments on the nominal trajectory above circular satellite velocity at 50,000 feet.

**SR,  $\Delta V$  Disp.** - the square root of the sum of the traces of the position or velocity dispersion covariance matrix partitions at the approximate docking interface (600-800 ft. range).

**SR,  $\Delta V$  Uncert.** - similar data for the uncertainty covariance matrix partitions.

Measurements out - time duration of periods when the sun interferes with measurements.

Examination of the data shown on Tables I and II, as well as the basic printed output of the program for the various cases considered, reveals that there are only four cases where sun-line interference on the optical tracker system would have a noticeable effect on the vehicle's performance. Of these, three cases were encountered where the position dispersions and position uncertainties at the docking interface were significantly larger than for the nominal case (no sun-line interference). This result is caused by sun-line interference in the terminal phase.

These three cases, in order of increasing dispersions and uncertainties, are as follows:

- a.  $180^\circ$  nominal transfer, low afternoon sun;
- b. MPAD transfer from  $+45^\circ$  longitude, low afternoon sun; and
- c. Low Double Hohmann, low morning sun.

The remaining troublesome case was for the  $230^\circ$  abort, high afternoon sun, where the summed  $\Delta V$  RMS was raised significantly (about 40 ft./second) over the nominal case because the first mid-course correction was delayed (optical tracker blanked out for approximately the first hour). The  $\Delta V$  required to complete the docking maneuver for cases a, b, and c, noted above, in comparison to the nominal case, is not known at this time. Recently completed docking simulation studies (to be published) on the Gemini vehicle, wherein dockings were made using visual cues only, have indicated an increase of about 25 ft./sec. in the  $\Delta V$  required to dock from 2000 to 3000 feet, compared to that required from the nominal docking range of 600 to 800 feet.

As can be seen on Table II, there are a few instances where the mid-course  $\Delta V$  RMS for the nominal case slightly exceeds that for certain sun-line interference effects. This is so because the guidance technique for the various transfers was not optimized for the nominal case. For the high Double Hohmann, high afternoon sun case, a large mid-course fuel penalty is noted on Table I. Lack of sighting information for a significant time period prevented a mid-course correction until about two minutes prior to the end of the first transfer. Since the guidance scheme employed nulled position at this point, a large correction was called for, and this large correction, in turn, had to be compensated for in the second phase of the high Double Hohmann. A logic to inhibit correction within some suitable range of the transfer point probably would have saved most of this penalty. In short, had the guidance system been optimized, it is unlikely that a severe  $\Delta V$  penalty would have been obtained for this case.

It should be stressed that the information presented above is preliminary, and only approximate in nature, for several reasons, the more important ones being as follows: The CSM uncertainties in position and velocity were not included in the simulation, the guidance schemes for the various transfers were not optimized, and only the extremes in sun-line interference were considered. It is felt that the data are of sufficient value, however, to conclude that the effects of sun-line interference on the optical tracker, in terms of vehicle  $\Delta V$  penalty, are not prohibitive for any of the transfers.

#### Concluding Remarks

The results of the present study have shown that sun-line interference effects generally require some increase in budgeted fuel. Although this increase is significant for certain transfer-sun-line orientation combinations, the penalty is not prohibitive. Because of the preliminary nature of this study, the data presented herein should be considered to show relative, rather than absolute, effects.

TABLE I. Results of the Sun-Line Interference Study

Transfer	Sun-Line	Mid-Course Corrs.	Mid-Course $\Delta V$ RMS, ft./sec	Term. Cor-rects.	Summed $\Delta V$ RMS ft./sec	Nominal $\Delta V$ ft./sec	$\delta R$ Disp. ft.	$\delta V$ Disp. ft/sec	$\delta R$ Uncert. ft.	$\delta V$ Uncert. ft./sec.	Measurements Out, sec.
180° Nominal	None	3	16.15	2	16.74	192.7	208.	1.20	92.	.19	None
180° Nominal	Lo Aft'noon	"	21.37	"	22.02	"	312.	1.24	247.	.25	0-780 2580-4020
130° Short	None	2	16.52	3	16.94	319.8	132.	.83	30.	.08	None
130° Short	Lo Aft'noon	"	24.05	"	24.69	"	140.	.88	"	"	0-840
230° Abort	None	4	35.58	"	36.58	327.7	189.	1.08	26.	.07	None
230° Abort	Lo Aft'noon	3	33.68	"	34.73	"	"	"	"	"	0-1260 2340-3960
230° Abort	Hi Aft'noon	"	70.40	"	74.58	"	256.	1.42	28.	"	0-3360
Lo Double Hoh.	None	3+1	19.91	2	21.77	192.4	248.	1.68	7.	.01	None
Lo Double Hoh.	Lo Morning	3+0	17.81	"	28.80	"	1318.	3.15	1241.	.95	3420-7160
Lo Double Hoh.	Hi Morning	3+1	19.90	"	21.90	"	378.	2.55	12.	.01	4260-6800
Lo Double Hoh.	Lo Aft'noon	"	21.69	"	23.53	"	246.	1.66	7.	"	0-360
Hi Double Hoh.	None	2+1	21.55	"	22.16	293.6	193.	1.29	9.	"	None
Hi Double Hoh.	Hi Morning	"	21.81	"	22.42	"	192.	"	"	"	360-540
Hi Double Hoh.	Lo Aft'noon	"	21.55	"	22.52	"	235.	1.48	73.	.09	2640-4080 6540-7760
Hi Double Hoh.	Hi Aft'noon	"	121.25	"	121.99	"	205.	1.36	10.	.03	1740-3480
MPAD (+ 45°)	None	1+2+2	27.55	"	27.64	220.5	119.	0.78	13.0	.02	None
MPAD (+ 45°)	Lo Morning	"	28.51	"	28.60	"	"	"	"	.06	2880-4080

TABLE I. Results of the Sun-Line Interference Study (page 2)

Transfer	Sun-Line	Mid-Course Corrs.	Mid-Course $\Delta V$ RMS, ft./sec	Term. Corrections	Summed $\Delta V$ RMS, ft./sec	Nominal $\Delta V$ , ft./sec	$\delta R$ Disp., ft.	$\delta V$ Disp., ft/sec	$\delta R$ Uncert. ft.	$\delta V$ Uncert. ft/sec.	Measurements Out, sec.
MPAD (+ 45°)	Hi Morning	1+2+2	28.21	2	28.30	220.5	119.	0.78	13.0	.02	3480-4740
MPAD (+ 45°)	Lo Aft'noon	1+2+1	25.37	"	25.59	"	615.	1.10	602.0	.59	6060-8100 8520-10200
MPAD (+ 45°)	Hi Aft'noon	1+1+2	25.46	"	25.55	"	119.	0.78	14.0	.02	5340-6840
MPAD (- 45°)	None	2+0+1	61.30	"	61.47	236.1	132.	1.00	11.	.02	None
MPAD (- 45°)	Lo Morning	1+1+1	23.39	"	23.57	"	"	"	"	"	3060-4380
MPAD (- 45°)	Hi Morning	2+0+2	63.51	"	63.60	"	122.	.91	"	.03	3720-5220



TABLE II. Transfer Times for Trajectories Considered

Transfer	Time, sec
180° nominal	4020
130° short	2466
Lo Double Hohmann	3431 for the first phase & 7160 for the complete transfer
Hi Double Hohmann	3591 for the first phase & 7760 for the complete transfer
230° Abort	4591
MPAD, +45° $\lambda$	3352 for the first phase, a total of 6821 for first two phases, & a total of 10,200 for all three phases
MPAD, -45° $\lambda$	3352 for the first phase, a total of 4910 for the first two phases and a total of 7653 for all three phases